

REPORT ON ACID MIST VENTILATION

ROMBAT Battery Plant
Bistrita, Romania

ENVIRONMENTAL ACTION PROGRAMME SUPPORT PROJECT
Contract DHR-0039-C-00-5034-0

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September 27, 1996

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EXECUTIVE SUMMARY

Chemonics International has undertaken projects at the ROMBAT battery plant in Romania as part of the Environmental Action Program Support (EAPS) project. EAPS is funded by the U.S. Agency for International Development (USAID) and managed by Chemonics International in Washington, D.C.

ROMBAT is a fully integrated manufacturer of lead acid storage batteries, principally SLI (starting, lighting, ignition) batteries for automobiles and trucks.

A major environmental problem at the plant is workplace ventilation, specifically control of lead fume and dust and sulfuric acid mist. Company management and the plant workforce want to improve ventilation, and ROMBAT has requested assistance in these areas as part of the EAPS project.

A Chemonics team including Liviu Ionescu, Philip Brown, and Michael Weiss visited the ROMBAT battery plant from August 20-23, 1996, to observe plant operations and gather data on the problem of acid mist in the battery charging area.

Acid mist is generated during the initial charging or *formation* of the batteries. The formation process has changed since the ROMBAT plant was built 16 years ago. The acid mist ventilation system designed for the original formation process is not effective under present operating conditions, and much of the ductwork, hoods, and mechanical equipment is no longer usable.

Workplace acid mist concentrations exceed allowable levels under Romanian law. The acid mist ventilation system must meet four requirements:

Remove acid mist from work area

Remove heat generated during formation

Prevent ambient acid mist emissions

Retain heat in plant during cold months

The Chemonics team identified short-term actions that could be taken to improve present acid mist conditions. These include modifications to existing equipment (removing ineffective hoods and ducts, determining which blowers are usable, using existing blowers for exhaust and make-up air), temporary installations to improve air flow (divider panels, battery supports in horizontal formation rooms, and hoods in vertical formation room), and development of information needed for design of a permanent system (heat load calculations, investigation of scrubbers, and mist eliminators).

The long-term solution to the ventilation problem is complete redesign of the acid mist ventilation system. Separate designs may be required for horizontal and vertical formation rooms. System design should include eliminating random air currents, using make-up and return air to cool batteries, and providing close capture hoods to minimize scrubber size.

SECTION I

INTRODUCTION

This report describes work undertaken by Chemonics International to assist ROMBAT, a Romanian fully integrated manufacturer of lead acid storage batteries, principally SLI (starting, lighting, ignition) batteries for automobiles and trucks. The work was conducted as part of the Environmental Action Program Support (EAPS) project, which is funded by the U.S. Agency for International Development (USAID) and managed by Chemonics in Washington, D.C.

EAPS activities in Romania are being implemented pursuant to the U.S. Government commitments under the Environmental Action Programme for Central and Eastern Europe (EAP) adopted in Lucerne, Switzerland in April 1993. As a signatory to the agreement, Romania has committed to cooperate with international donor institutions and Western governments to implement the terms of the agreement through policy reforms, environmental action plans, and investment aimed at improving environmental conditions and reducing health risks.

The ROMBAT plant is 16 years old. Original production equipment was purchased in the United States, Germany, Bulgaria, and Romania. All environmental control equipment was made in Romania. From the beginning, ROMBAT operation experienced production, quality, maintenance, and environmental problems

In May 1996, ROMBAT became fully privatized, completing a process begun in February 1994. The company was purchased from the Government of Romania (GOR) by management and workers. There is no significant ownership by outside groups or investment funds.

Since 1990, the company has worked to improve equipment, processes, and productivity. Production equipment has been imported from the United States and Italy. In 1996, plant output is expected to be 1.8 times the output of 1989. Production is 2,000 to 2,500 batteries

a day, with 1996 production projected for 450,000 units.

Production is 95 percent automotive batteries, mostly for the replacement market. Daewoo, the Korean automobile manufacturer, is currently evaluating ROMBAT batteries for original equipment in cars it will produce at its new Romanian plant.

ROMBAT exports a portion of its production; the company has a current contract for 50,000 units for export to Russia at a rate of 6,000 per month through March, 1997.

The first activity at ROMBAT on the EAPS project was occupational respiratory protection program training, including a ~~A~~knowledge, attitude, and processes® (KAP) study. The KAP study involved interviews with professional employees and plant operators to determine their operating knowledge on respiratory protection, attitudes toward respiratory protection in the workplace, and current protection practices.

The study found there was strong concern by plant workers over inadequate hygiene ventilation. ROMBAT management agrees there are problems with hygiene ventilation and is anxious to make improvements.

Ventilation areas that need to be addressed include the following:

Lead dust and fumes in the grid casting, oxide production, paste production, and assembly areas

Acid mist in the forming or charging area

ROMBAT has done some work to improve lead fume and dust collection, but little regarding acid mist control. The work addressed in this report is concerned with improving acid mist ventilation.

A Chemonics team composed of Liviu Ionescu, Philip Brown, and Michael Weiss visited the ROMBAT battery plant from August 20-23, 1996, to gather information for the acid mist ventilation improvement task. They toured the entire plant operation, with emphasis on the formation department; discussed the acid mist problem with ROMBAT technical and management personnel; and reviewed third-party technical studies of the area provided by ROMBAT.

SECTION II

DESCRIPTION OF OPERATIONS

A. Plant Production Process

ROMBAT is a fully integrated battery manufacturing plant, producing virtually all battery components from the following raw materials:

- \$ Concentrated sulfuric acid for paste production and electrolyte
- \$ Pure lead for lead oxide production
- \$ Lead alloys for grid and miscellaneous part production
- \$ Plastic pellets for case fabrication
- \$ Polyvinyl chloride (PVC) strip for separators

Following are the major portions of a battery:

- \$ *Grids*, which hold the paste and conduct electricity from the paste
- \$ *Paste*, or active material, which generates electricity through a reversible chemical reaction
- \$ *Acid*, or *electrolyte*, which takes part in the reaction
- \$ *Separators*, which allow electrolyte to contact the grids while preventing physical contact between positive and negative grids
- \$ *Straps* and *posts*, which join the grids and form external connections
- \$ *Case*, which holds the entire assembly

Battery grids are cast from lead alloys on nine grid casting machines. Five older

machines are of Romanian manufacture; four new machines were made by Wirtz, a U.S. company.

In grid caster operation, metal is pumped from a melt pot into a two-part permanent mold. The mold opens to discharge the solidified grid, which is automatically trimmed and stacked. Trimmings and the grids rejected by the operator are transferred back to the melt pot on a conveyor. Acceptable grids are stored for age hardening.

The newer grid casters with sophisticated instrumentation and control systems can produce grids from a full range of antimonial lead alloys and calcium lead alloys. The older casters are limited to production of grids only from antimonial lead alloys with higher antimony contents.

Lead oxide is made from pure lead by the Barton process. While three lines are available, two are generally operated, with the third available as a spare. Lead is melted in small pots, then admitted in controlled amounts to a small reactor. In the reactor, a rotating impeller disperses the molten lead stream into fine droplets. The reactor is under negative pressure, so air is drawn in to form lead oxide. The oxide is separated from the exhaust air stream through a system of cyclones and a baghouse. Factors important to producing oxide with desirable characteristics include reactor temperature, air flow, metal flow, and oxide temperature.

Oxide is mixed with dilute sulfuric acid to form lead sulfate paste for positive and negative grids. The negative paste also includes expanders containing barium sulfate, carbon, and plastic flakes.

Paste is squeezed onto grids automatically. The pasted grids are dried in a tunnel kiln, then stored to age.

Small parts, such as posts and lugs, are hand cast from lead alloys in book molds. These parts are used to connect the grids and provide external battery connections.

Battery cases and tops are injection-molded from polypropylene. Some cases for large truck batteries are made of bakelite.

Separator envelopes are formed from PVC strip as the positive and negative plates are assembled into groups. These groups are manually assembled in the battery boxes by hand soldering connections between the groups. Tops are added to the boxes and units are sealed and checked for leaks.

Batteries are taken to the formation area for charging. At the formation area, batteries are filled with acid by immersion in a large vat. This process overfills the batteries, resulting in losses through spillage and potentially increased acid mist generation during formation. ROMBAT has recently purchased an automatic filling machine to control acid addition.

The sulfuric acid used in charging has a different concentration from the electrolyte used in the battery, so the formation acid is dumped and the electrolyte added to the charged batteries.

Finally, the charged batteries are tested, labeled, and shipped.

B. Formation Process

Formation refers to the initial charging of batteries. Batteries are connected to a source of direct current (D.C.) electricity for charging. In the process reactions, lead sulfate on the positive grids is converted to lead dioxide (PbO_2), and lead sulfate on the negative grids is converted to metallic lead. These reactions are the opposite of those that occur when a battery is discharged.

In the original ROMBAT plant design, individual cells were immersed in acid and electrically connected for formation. Charged cells were then assembled into completed batteries. This method is now used only on large cells for industrial batteries. Photograph 1, Annex D, shows the tanks with industrial plates being charged.

The present practice on most batteries is formation after batteries are fully assembled. Batteries are filled with acid, then taken to rooms for formation. Batteries are either arranged horizontally on platforms or vertically in racks. In each case, batteries are connected electrically in series, and current and voltage is applied. Current and voltage are varied

through the charging cycle.

One room, approximately 4 meters (m) wide and 29.5 m long, is used for formation of individual cells. Two rooms, each 20 m by 29.5 m, are used for formation in horizontal arrangement. Two rooms, approximately 9 m wide by 27.5 m long, are used for formation in vertical arrangement, and a third room for formation in vertical arrangement is being prepared. This room is of similar size to the other vertical formation rooms.

For horizontal arrangement, batteries are manually wheeled on carts to the formation rooms, placed in three parallel lines on a pedestal, and electrically connected. Photograph 2 shows the pedestals, and photographs 3 and 4 show batteries in the horizontal arrangement. The pedestals were originally designed to support acid tanks for individual cell charging.

Set-up for formation in the horizontal arrangement takes two men 30-120 minutes, depending on the number of batteries. Charging takes 24-38 hours, depending on ambient temperatures. Disconnecting the charged batteries takes two men up to 30 minutes. A total of five men per shift are required for horizontal charging. During set-up and take-down, workers are exposed to acid mist.

Battery formation on vertical racks is shown in photograph 5. Presently, only larger truck battery formation is done in this way, although the plant would like to increase formation on vertical racks to improve labor efficiency and reduce employee exposure to acid mist. On the vertical system, batteries are loaded on pallets outside the acid mist area and moved by forklift to the formation room. Pallets are placed in the racks and batteries are connected in 30 minutes. Charging takes 32 hours. Only two employees, the forklift driver and the electrician who makes the connections, are exposed to the acid mist.

Heat generated during formation is a major problem at ROMBAT. The plant believes the ideal electrolyte temperatures during charging are 40E- 48EC, but ROMBAT operates at maximum electrolyte temperature of 60EC. Higher temperatures occur because of the higher current densities ROMBAT uses during formation to meet production requirements. The formation process limits on plant output, so increasing current density reduces formation time, thus increasing production.

C. Summary of Emission Controls

Emission control systems were designed by Electroproiect, a Romanian engineering institute.

Three ventilation baghouses were originally provided for the grid, oxide, and paste production areas, and five baghouses on the assembly area. The baghouses are of Romanian manufacture. All eight baghouses appear identical: single cells with reverse air cleaning. Each has an induced draft blower and smaller blower for bag cleaning.

Originally, 17 systems were installed for acid mist collection, each system complete with hoods, ducts, a scrubber, and blower. Hoods, ducts, scrubber housings, and blower housings were fabricated from PVC and blower wheels from stainless steel. Dampers and ducts were designed to allow returning a portion of the scrubbed air to the workplace and exhausting the balance to the atmosphere.

SECTION III

ACID MIST VENTILATION

A. System Description

The 17 scrubber systems originally provided for acid mist control were designed for formation of cells in acid tanks similar to that shown in photograph 1 of Annex D. The original hoods, which may have been suitable for cells in tanks, are not effective in capturing acid mist generated during the formation of whole batteries.

Nine scrubber systems currently are connected to areas of cell formation in tanks and formation of batteries in horizontal arrangement, and eight scrubber systems are connected to areas where batteries are formed in a vertical arrangement. Each system includes hoods, collection and return ductwork, a scrubber, a blower, and a stack. Design capacities are summarized in Table III.1.

Table III.1. Acid Mist Collection Systems (Flows in Cubic Meters/Hour)

System	Design Flow	System	Design Flow
1	40,000	10	20,000
2	30,000	11	40,000
3	30,000	12	40,000
4	30,000	13	20,000
5	20,000	14	40,000
6	40,000	15	20,000
7	40,000	16	40,000
8	20,000	17	20,000
9	40,000		

According to the ROMBAT process engineer for the formation area, the ventilation system must help control battery temperature during formation as well as exhaust the acid mist. These two requirements can be in conflict in colder times of the year when air removed for mist control will also remove heat from the building. This is the main reason for the provision to recirculate cleaned air.

During formation, battery electrolyte temperature is controlled to a maximum of 60EC. At this temperature, the batteries are too hot for constant touch. The electrolyte must be maintained below 65EC to prevent decomposition of water. Every two hours a worker checks the electrolyte temperature. Temperature is controlled by adjusting the current density.

In winter months, battery formation is achieved in 24 hours in the horizontal arrangement, while in the summer formation may take as long as 38 hours. The difference in time is due to improved heat removal during formation in colder weather.

The electrolyte temperature varies with the position of the batteries in the horizontal arrangement. Three rows of batteries are connected (photographs 3 and 4), and those on the center row have less air circulation and therefore higher electrolyte temperature. Better air circulation around the batteries is desired.

Formation of batteries on vertical racks (photograph 5) results in better use of space, but the denser arrangement of batteries means the heat generated in formation is not as easily removed. This results in the longer formation cycle for batteries in the vertical arrangement versus the horizontal arrangement.

If the heat could be removed so charging times on vertical racks were the same as on the horizontal arrangement, the vertical arrangement would provide a 30 percent improvement in production per sq m of floor area.

B. Condition and Performance of Systems

While all 17 acid mist ventilation systems have problems, those in the horizontal forming rooms are generally in worse condition than those in the vertical formation rooms. The vertical formation arrangement is new. As a result, the vertical formation rooms and the associated ventilation systems had not been used for some time and had not been damaged in use.

Virtually none of the hoods in the horizontal forming rooms are working. Most ducts have been disconnected from the hoods or have large holes broken out. No air movement could be felt at hoods or duct openings checked.

Some air movement could be detected in the vertical formation rooms. In these rooms, hoods had been removed leaving only stub connections to the ducts. There is less damage to main ducts in the vertical formation rooms than in the horizontal formation

rooms.

ROMBAT provided a report on the ventilation systems prepared in 1994 by the Scientific Institute for Occupational Safety. This report covered only the nine systems in the horizontal and cell formation areas. The measured flows compared to design flows are shown in Table III.2.

Table III.2. Acid Mist Collection Systems (Volumes per System in Cubic Meters/Hour)

System	Design	Actual
1	40,000	23,270
2	30,000	20,678
3	30,000	24,569
4	30,000	27,706
5	20,000	17,413
6	40,000	28,529
7	40,000	28,896
8	20,000	14,764
9	40,000	29,808

Source: Measurements Regarding Effect of Ventilation Systems in Charging Area and Central Ventilation, Scientific Institute for Occupational Safety, May, 1994.

During the 1994 study, the scrubbers were not functioning as chemical scrubbing units. Temporary repairs were made to water sprays so scrubber performance could be checked. Table III.3 shows the results on the nine scrubbers with and without operating water sprays. The sprays have little effect on acid mist removal or the acid mist in scrubber discharge air.

Table III.3. Acid Mist Concentrations (Milligrams per Cubic Meters)

Scrubber	Inlet	Outlet ^c no spray	Inlet	Outlet ^c with spray
1	1.79	1.20	1.87	1.17
2	1.72	1.18	1.69	0.97
3	1.70	1.11	1.72	0.91
4	1.69	0.90	1.74	0.96
5	1.67	0.96	1.69	0.91
6	1.84	1.18	1.81	1.18
7	1.81	1.06	1.80	1.01
8	1.75	0.95	1.78	0.94
9	1.83	1.06	1.82	1.05

Acid mist limits ROMBAT must meet are 0.50 mg/cubic meter for plant average and 1.0 mg/cubic meter for peak exposure. Table III.4 presents the results of measurements by the Scientific Research Institute for Occupational Safety taken in 1994, a period when production was much below present levels. Notice in all cases the spot readings exceed the regulatory limit for average exposure, and many are above the peak exposure limit.

In November 1995, the Sanitary Police took a spot measurement of 2.7 mg/cubic meter in the middle of the formation department. Romanian ambient air standards for sulfuric acid mist are 0.03 mg/cubic meter for short-term peak emission and 0.012 mg/cubic meter for daily average.

Table III.4. Acid Mist Concentrations^c Breathing Zone (Milligrams per Cubic Meters)

Forming Automobile Batteries		Forming Truck Batteries		Forming Plates	
Spot	Average	Spot	Average	Spot	Average
0.87 1.03 0.98 0.78 1.39	1.01	1.72 1.36 0.98 0.95 0.90	1.182	1.43 0.92 1.36 0.98 0.91	1.12
0.61 0.88 0.90 0.69 0.93	0.802	1.83 2.02 1.52 1.30 1.03	1.548	1.29 0.88 0.89 1.10 0.90	1.012
0.79 0.89 1.01 0.75 0.78	0.844	0.98 1.01 0.94 1.02 1.04	1.002	1.27 0.85 0.87 0.92 0.90	0.96

1.07 0.56 0.62 0.85 0.91	0.802	0.96 0.99 0.87 1.51 0.98	0.962		
0.93 0.77 0.80 1.07 0.93	0.90				

Source (Table III.3 and III.4): **A**Measurements Regarding Effect of Ventilation Systems in Charging Area and Central Ventilation, ©Scientific Institute for Occupational Safety, May 1994.

The acid mist ventilation equipment is in poor shape, but ROMBAT said the ventilation system never had operated well. Observation of the existing hoods and ducts reveal many poor design practices, in some cases due to physical restrictions of the building. Ducts have many bends, often with small radius, and frequent changes in cross-section. Fan connections have short inlets and outlets with right angle bends and tee branches. Photographs 6 and 7 illustrate the problems with blower outlets.

Several blowers were not operating. Some that were operating vibrated noticeably. Belt drives on some blowers were loose, and others were missing belts.

The horizontal process rooms have an access hall on each end. One access hall is along an exterior wall with translucent panels. With backlighting from the wall panels, faint mist clouds could be seen in some areas. Acid mist drifted from the batteries without visible flow pattern.

SECTION IV

DISCUSSION AND RECOMMENDATIONS

Most of the ROMBAT plant's existing installation or equipment is no longer usable. Some blower wheels may have remaining life, but 16 years of operation have taken their toll in erosion and wear.

Hood design is not suitable for present formation practices, and much of the main duct work has been damaged or destroyed.

The acid mist control system must fulfill four functions:

- \$ Remove acid mist from work area
- \$ Remove heat generated during formation
- \$ Prevent ambient acid mist emissions
- \$ Retain heat in plant during cold months

The exhaust system design for ROMBAT provided for 1 to 1.5 air changes per minute (see calculations in Annex A). An attached description of acid mist exhaust system at a U.S. battery plant indicates a higher air replacement rate of 1.75 air changes per minute. Depending on cooling requirements, the lower air movement can be effective with enclosures around batteries for mist capture and removal during formation.

In the large rooms for horizontal formation, there is considerable random air motion and uncontrolled flow. Acid mist emitted from batteries drifts through the rooms. Much uncontrolled air movement is caused by motion of people and material handling equipment. The effects of random flows can be reduced by dividing the large rooms into smaller rooms.

The forklift used in the formation department is large with a turning radius that requires wide access lanes. More maneuverable material handling equipment might allow stacking of batteries on pallets for horizontal formation out of the exposed area. This equipment could also allow formation rooms to be redesigned with greater density of battery racks or platforms per square meter.

As a long-term solution, ROMBAT should replace the existing system with one designed for the present formation process and equipment. This will take some time and

capital funds, but there are some actions that can be taken in the short term to improve the acid mist ventilation.

A. Recommendations for Short-Term Activities

The following short-term actions can improve the acid mist ventilation with minimal capital investment. These changes will not reduce the acid mist to required levels, but they should make noticeable improvements in working conditions (See Annex B). The following recommendations are listed in priority order, although some activities can occur simultaneously. For example, items 2 through 4 are independent of item 1.

1. Calculate heat removal requirements from energy balance: energy in minus energy required for formation.

Comment: Absolute necessity for design of future systems and to help evaluate short-term modifications. No material cost involved.

2. Remove present hoods in horizontal formation rooms.

Comment: Cost and effort are low. Hoods will be scrapped eventually. Action necessary to carry out item 3.

3. In the horizontal charging rooms, install vertical panels from existing support structure along the middle of the pedestals. These panels will protect workers connecting or disconnecting one set (three lines) of batteries from fumes and mist drifting from an adjoining set of batteries.

Comment: Simple and low-cost action for noticeable improvement in working conditions.

4. Install pallets or grid supports to elevate batteries in horizontal formation arrangement for better cooling through improved air circulation. Add identical supports on deck of transfer cart to match higher elevation of batteries so workers will not have to lift batteries from cart.

Comment: Medium to high cost for materials and fabrication. This change is made more effective by adding make-up air at low level.

5. Examine all 17 blowers to determine whether the wheels are usable or whether they have corroded excessively. Restore the blowers with good wheels to design operating conditions by balancing the wheels and replacing worn bearings and drives where required.

Comment: Low to medium cost, but necessary for other changes. Operating

cost of ineffective fans will be eliminated.

6. Install simple hoods over the racks in the vertical charging rooms. Height restrictions may limit these to flat pieces, but they will be more effective than the present open connections.

Comment: Low to medium cost. Hoods are simple to construct and may be part of future full enclosures around racks. Hoods over the racks will improve acid mist removal even with existing exhaust systems.

7. Remove existing return air ducts. Acid mist levels in scrubber exhaust exceed allowable limits for worker exposure, so the air should not be recirculated.

Comment: Medium cost and effort. Some return air is minimal already, but removing ducts will improve present situation.

8. Based on available volume from the repaired blowers, connect some blowers to bring in fresh make-up air, and the remainder to exhaust air from the formation rooms. More air should be exhausted than is brought in to keep the rooms under negative pressure. The actual exhaust/make-up split is dependent on the available fan capacity.

Comment: Medium cost because fabrication or extensive modification of ducts is required.

9. Introduce 80-90 percent of the make-up air at or near floor level to provide circulation of air and acid mist to the hoods and prevent formation of stagnant air layers. The rest of the make-up air should be brought into the hall area outside the rooms. This air will then be drawn into the rooms, preventing escape of air and acid mist into adjoining work areas.

Comment: Medium cost for duct fabrication, but important to maximize performance of remaining exhaust systems.

10. Investigate mist eliminators or different scrubber designs. Size, price, and performance information should be obtained from equipment manufacturers.

Comment: ROMBAT is planning to purchase and install a mist eliminator manufactured by the German firm Kustan. Literature on this unit and information from a U.S. manufacturer are included in Annex E to this report.

11. Purchase a smaller forklift for moving batteries in and out of formation rooms. Consider electric-powered unit rather than diesel.

Comment: High cost item. Increased maneuverability will improve handling of batteries and will establish the dimensions for future formation rooms.

An electric unit will reduce worker exposure to noxious and sometimes hazardous exhaust fumes. As a battery manufacturer, ROMBAT should use electric-powered equipment wherever possible to illustrate advantages of battery power.

B. Long-Term Design Considerations

The long-term, permanent solution is to completely redesign the acid mist ventilation system. Separate designs may be required for horizontal and vertical formation rooms, including make-up, exhaust, and recirculated air. The following design issues should be considered in making permanent changes to the acid mist ventilation system (see Annex B):

1. Provide make-up air under and around batteries for enhanced cooling.
2. Replace pedestals in horizontal room with support structures that include make-up or return air supply plenums for better air flow. Top of supports should be fiberglass grids for good air flow around batteries.
3. Install permanent walls to reduce size of horizontal formation rooms. This will reduce cross drafts and other uncontrolled air movement. The smaller rooms should each be provided with independent ventilation systems for better control.
4. For vertical formation arrangement, consider cabinets or enclosures around racks. Each enclosure would have exhaust and supply air connections.
5. Combine exhausts from individual systems into common stacks (or one stack). This will reduce the number of point sources to be sampled and associated sampling costs.

C. Recommended Future Action

After ROMBAT and EAPS reach agreement on short- and long-term activities, ROMBAT and EAPS should complete a schedule of activities and expected completion dates. The schedule should be sufficiently detailed to track key steps on individual activities. For example, installation of vertical panels in horizontal formation rooms (recommended activity 3) may be divided into *purchasing material* and *installation* as separate items for better control.

A bar chart similar to a Gantt progress chart will be useful to show where simultaneous work can take place to minimize overall completion time. Again, using activity 3 as an example, installation of vertical panels can start in areas where old hoods have been removed (activity 2) without waiting for all the hoods to be removed. There is no need for an elaborate schedule such as a PERT chart on the short-term activities because much of the work involves independent projects.

Scheduling should identify activities that will involve design, such as hoods and ducts. EAPS and ROMBAT will have joint responsibility to develop design. ROMBAT will estimate fabrication and installation costs after designs are agreed upon.

Preliminary design of interim hoods and ducts can be completed four weeks after a schedule is agreed to. Final design will depend on evaluation and repair to existing blowers.

ROMBAT and EAPS will each develop cost and delivery estimates for potential scrubbers and mist eliminators (recommended activity 10). ROMBAT can evaluate European sources and EAPS American manufacturers. Because design flows on a new system will not have been developed, units for air flows of 10,000 Nm³/hr, 20,000 Nm³/hr, and 40,000 Nm³/hr should be evaluated.

ANNEX A CALCULATIONS

Tri-Mer Case History (Annex E): Exhaust rate 180,000 CFM for room 206 ft x 45 ft x 11 ft = 101,970 cubic feet. Air changes per minute = $180,000/101,970 = 1.77$

ROMBAT Horizontal Arrangement: Exhaust rate = Systems 1-3 and 5-9: 260,000 CMH for room 40 m x 29.5 m x 3.5 m = 4,130 cubic meters. Air changes per minute = $260,000/4,130/60 = 1.05$

ROMBAT Vertical Arrangement: Exhaust rate = 60,000 CMH or 80,000 CMH for room 9 m x 27.5 m x 3.5 m = 866 cubic meters. Air changes per minute = $60,000/866/60 = 1.15$ or $80,000/866/60 = 1.54$

ANNEX B DRAWINGS

RB-SK1: Concept Enclosure for Vertical Formation

RB-SK2: Concept Short-term Changes to Horizontal Formation Rooms

RB-SK3: Concept Long-term Changes to Horizontal Formation Rooms

ANNEX C
PERSONS CONTACTED

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Ms. Elena Fortuneanu Head of Health, Safety and Environmental Areas

Mr. Valentin Lostun Process Engineer in Formation Department

Mr. Gavril Tofan Chief of Maintenance

ANNEX D PHOTOGRAPHS

Photo 1: Formation of Individual Cells

Photo 2: Existing Pedestal Construction

Photo 3: Horizontal Formation Arrangement

Photo 4: Horizontal Formation Arrangement

Photo 5: Vertical Formation in Racks

Photo 6: Duct Exiting Blower

Photo 7: Duct Exiting Blower

Photo 8: Individual Exhaust Stacks from Scrubber Blowers

ANNEX E VENDOR LITERATURE

Kustan Droplet Separator

Tri-Mer Corporation

